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Joe Warne
Technological University Dublin, joe.warne@tudublin.ie

Allison H. Gruber
Indiana University

Roy Cheung
Hong Kong Polytechnic University

See next page for additional authors

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Original Research

Training and technique choices predict self-reported running injuries: An international study

Joe P. Warne [a, b, *], Allison H. Gruber [c], Roy Cheung [d, e], Jason Bonacci [f]

[a] Department of Applied Science, Technological University Dublin- Tallaght Campus, Dublin, Ireland
[b] Setanta College, Thurles Chamber of Commerce, Tipperary, Ireland
[c] Department of Kinesiology, School of Public Health, Indiana University, Bloomington, IN, USA
[d] Department of Rehabilitation Sciences, Hong Kong Polytechnic University, Kowloon, Hong Kong
[e] School of Health Sciences, Western Sydney University, Campbelltown, NSW, 2560, Australia
[f] Centre for Sports Research, School of Exercise and Nutrition Sciences, Deakin University, Waurn Ponds, VIC, 3216, Australia

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A B S T R A C T

Objectives: The aim of this study was to describe the self-reported injury, training, and running technique choices of regular runners in four international regions.
Design and setting: 756 participants began an expert derived self-report online survey in Ireland, USA, Hong Kong and Australia.
Participants: 325 participants completed the survey (age = 38 ± 10 years; weight = 68.0 ± 13.1 kg; height = 1.70 ± 0.10 m).
Main outcome measures: Descriptive statistics are reported examining injury incidence and location; shoe and orthosis choices; and training and technique practices. A backwards logistic regression was implemented to examine associations between injury and training choices.
Results: 68.3% reported having an injury in the last year. 81.45% of these injuries were believed to be running related. A large variation in training and footwear choices were observed for respondents. The regression ($P \leq 0.001$) explained 20% of the variance in injury selection (Nagelkerke R^2) and was able to identify 73% of cases accurately. Associated injury factors included competitive running, running on more than one surface, younger age, having a lower running age, and a higher proportion of running at an easy intensity.
Conclusions: The high amount of variability in runner's choices highlights the lack of consistent information being presented to them and may be the reason for the high injury incidence.

1. Introduction

Running as a form of physical activity and sport remains extremely popular worldwide (Running USA, 2019), because the convenient and accessible nature of this activity makes it appealing to a large majority of people (Lee et al., 2017). However, the frequent injury incidence in running remains a concern over the last decade (van Gent et al., 2007; Kluitenberg et al., 2015a; Van Der Worp et al., 2015; Videbæk, Bueno, Nielsen, & Rasmussen, 2015), and recent self-report research suggests injury rates are unchanged or increased (Costa, Fonseca, Oliveira, Araujo, & Ferreira, 2020; Wiegand et al., 2019). These injuries can carry a psychological cost of triggering mental health issues (Putukian, 2016), and monetary cost of up to $10,000 USD per injury due to pain management, recovery time, and said influence on mental health (Hespanhol Junior et al., 2013; Knowles et al., 2007). Therefore, research is required to understand the prevalence and nature of these running injuries. The study of these injury risk factors is ongoing, but given the multifactorial nature of said injuries, results so far have been varied.

One reason for the inconsistencies in injury risk factors may be the wide variety of training practices selected by the running population. Runners are faced with an overwhelming array of training choices that have been associated with injury incidence; these most commonly include factors such as running experience, volume, intensity, and frequency (Tonoli, Cumps, Aerts,

* Corresponding author. Technological University Dublin - Tallaght Campus, Blessington Rd, Dublin, 9, Ireland.
E-mail address: Joe.warne@tudublin.ie (J.P. Warne).

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Verhagen, & Meeusen, 2010; Van Gent et al., 2007; van Mechelen, 1992; Yeung & Yeung, 2001), or level or frequency of competition (Murphy, 2003; van Mechelen, 1992). However, experimental studies have yet to reveal any training programs that clearly reduce overall injury rates (Craig, 2008; Nielsen et al., 2014; Yeung et al., 2011). A training factor often overlooked is variability in the locomotor-surface interaction; Some authors have proposed that increased training surface variability may be associated with reduced injury risk (Malisoux et al., 2015), given that the chronic stressors will not be as consistent and specific (Hamill, van Emmerik, Heiderscheit, & Li, 1999; Hamill et al., 2012). In addition, there is belief that changing the running technique (Kozinc & Sarabon, 2017), as well as being involved in multiple sports (Malisoux et al., 2015) may be associated with reduced injury risk, but this remains to be fully explored. Therefore, obtaining data related to running surface, technique choices, as well as participation in other sports/activities requires documentation.

Footwear may also be a tool to change the locomotor-surface interaction (Kurz & Stergiou, 2003), and runners have numerous footwear choices available (including barefoot and minimal shoes) which has experienced significant debate in the scientific literature (Nigg et al., 2017; Richards et al., 2009; Warne & Gruber, 2017; Wen et al., 1998; Yeung et al., 2011), in addition to in-shoe options (i.e. insoles, orthotics) (Bonanno, Landorf, Munteanu, Murley, & Menz, 2017; Chang et al., 2012; Mattila et al., 2011). Both footwear and in-shoe options have seen extensive research but as yet, no clear consensus statement with respect to injury exists despite the fact that this is a viable injury prevention method (Saragiotto et al., 2014). A diversity of choices and varied evidence highlights the need for more research across a wide range of running populations in order to better inform us of current practices.

Runners beliefs about injury prevention is varied and often not evidence based (Saragiotto et al., 2014), because what may be considered a safe and appropriate option for a given runner may be influenced by popular media, word-of-mouth, or other non-experts, and clarification should be sought with scientific research. To date, we are not aware of any literature that has sought to examine a range of choices made by runners worldwide in relation to injury risk. With regard to the generalisability of such research, international cohorts are rarely examined, despite the fact that research is digested worldwide and is not interpreted as race or nationality specific.

One challenge with developing a better understanding of running injuries is the difficulty in gathering large datasets from a prospective cohort; for example, Videbæk, Bueno, Nielsen, & Rasmussen, 2015 in a meta-analysis identified that only thirteen studies on this topic were published between 1987 and 2014. Therefore, more frequent information such as that gained from injury surveys present a cost-effective and feasible method of progressing our understanding of current injury status and allows for more regular “snap-shots” of running injury information. Such surveys also allow us to develop potential associations to injury risk factors within large, international cohorts that can then be explored further in experimental trials.

Therefore the aim of this study was to describe the self-reported injury, training, and running technique choices of regular runners in four targeted international regions from the last year. Secondly, we aimed to examine if self-reported injury incidence could be predicted by said training and technique choices. We hypothesised that training choices related to volume, or intensity, as well as training age, would be predictors of injury in the last year.

2. Methods

2.1. Participants

756 participants were recruited to complete the survey via social media adverting using the catch line “Are you a runner, over 18 years of age, where running is your primary sport/activity?“. Advertising took place in Ireland, USA, Hong Kong and Australia via paper fliers posted near university areas and through social media. Independent ethical approval was granted in Technological University Dublin, Indiana University, Hong Kong Polytechnic University, and Deakin University. The survey involved a digital informed consent that was completed prior to beginning the survey questions.

2.2. Experimental design

A survey was designed by 4 recognised authors in the field of running science collaboratively written and administered using Qualtrics (Provo, Utah, USA). This survey intended to examine the following areas: injury incidence, injury type and diagnosis; shoe and orthosis choices; and training and technique practices. Initial sections and questions were proposed and agreed upon by the panel. The survey was then examined for face validity by independent readers, and then comprehension and response accuracy were established in each country using 20 total participants ($N = 5$ participants per country or region). This process involved participants completing the survey in full, and then being interviewed in relation to their responses in which the participants were asked “What do you think this question is asking you?” and “Explain how you arrived at the answer you provided”. The results were compiled into a summary report and subsequently used to improve the clarity and structure of the survey. All units were available to be reported in imperial or metric units, as per the respondent’s choice. We also established consistent terminology to distinguish between common differences across continents in the use of certain words/phrases. We used choice randomisation and neutral spacing in multiple choice questions to eliminate response bias. In addition, filter questions using skip logic were applied such that respondents did not have to answer any questions of which a previous response had made such question irrelevant. For example, if a respondent did not report an injury, they were directed past the section on injury information to the following section.

2.3. Question specifics

The following definitions and explanations were provided for clarity to participants in each relevant section; an “injury” was defined by any pain or discomfort that resulted in missing at least two days of training, and/or required treatment from a medical professional. Injury severity was described as “minor: slowed pace, same weekly routine”; “mild: slowed pace and decreased weekly mileage”; “moderate: stopped running for less than one week”; “serious: stopped running for 1–4 weeks”, and “severe: stopped running for more than 1 month”. When asked about interest in barefoot or minimalist footwear running, minimalist shoes were defined as “ultra-minimal shoes such as foot gloves, flexible with a very thin sole”, to avoid confusion with lightweight conventional shoes. Regarding how many different shoe types the respondents run in regularly, we clarified “please include running barefoot as one shoe type if it applies”.

2.4. Data processing

Participants responses were included in the final analysis if the survey has been fully completed, digital consent was received, and respondents were above 18 years of age. Text entry responses were voided if a response was not clear, had the question been misinterpreted, or any obvious error was noted. All units were converted into metric values. Data was cleaned for typographical and interpretive errors. Free text responses were minimised by including “select all that apply” or otherwise including an “other” open text response. For the regression analysis, where categorical responses resulted in low frequencies, grouping was applied. For example, the “highest level of competition” required respondents to select international, regional, charity race, etc. from a total of 11 options, which was subsequently summarised into just three categories as “competitive, recreational competition, non-competitive” to achieve a minimum $N \geq 10$ in each category for regression analysis.

2.5. Data analysis

Descriptive statistics were established for continuous (mean ± SD [95% confidence interval]) and categorical data (frequencies) for the primary aim. The secondary aim was examined using a backwards conditional stepwise logistic regression, with injury status (Injured in the last year? [Yes/No]) as the dependent variable. No multicollinearity was observed (all variance inflation factor [VIF] <2). Independent variables included in the analysis are listed in Table 1. All planned variables relating to training characteristics or technique choices were included in the analysis with no selective inclusion criteria applied. However, one variable, the use of barefoot or ultra-minimal shoes, was omitted from the analysis because N = 27 reported spending more than one month running in this footwear. Therefore, the sample size was insufficient to explore the effect of these footwear types on injury without inflating the risk of error. Whilst other unrelated variables were collected in the survey, those variables were not included in the present analysis because they were not directly related to the specific research question. Analysis was conducted using SPSS (Statistical Package for the Social Sciences data analysis software V20.0, SPSS Inc., Chicago, Illinois, USA). Statistical significance was accepted where $\alpha = 0.05$.

3. Results

325 participants completed the survey in full and met the inclusion criteria (age = 38 ± 10 years; body mass = 68.0 ± 13.1 kg; height = 1.70 ± 0.10 m; running experience = 10 ± 10 years; gender split = males 51.7%/females 48.3%). The descriptive statistics of training choices reported by respondents can be observed in Table 2.

For injury incidence, 68.3% (N = 220) of respondents reported having an injury in the last year. Within the 325 respondents, a minimum of 387 total injuries in the past year were reported; 43.8% (N = 95) reported one injury, 39.2% (N = 85) reported two injuries, 13.8% (N = 30) reported three injuries, 1.4% (N = 3) reported four, 1.8% (N = 4) reported 5 or more, and N = 3 did not specify. Of the total injuries reported, 81.4% (315 injuries) were believed to be running related, 8.8% (34 injuries) were unknown in cause, and 9.8% (38 injuries) were not running related. 58.1% (216) of these injuries were diagnosed by a medical professional, 40.8% (N = 152) were self-diagnosed, 1.1% (N = 4) by other parties (e.g. chiropractor, acupuncturist, spinologist) and N = 15 did not specify. The anatomical location of the reported injuries can be observed in Fig. 1. The injury severity was described as severe in 25% (N = 93) of cases, serious in 30% (N = 112), moderate in 20% (N = 75), mild in 19% (N = 73), and minor in 6% (N = 24).

Orthotic devices or prescribed insoles were used in the last year by 21.5% (N = 68) of respondents. Within this group, 64.2% (N = 43) were prescribed or wore orthotics due to a previous injury, and 78.6% (N = 33) reported that the orthotic/insole resolved the specific injury. 16.7% (N = 7) reported that orthotic use did not resolve

Table 1
The variables included and not included in the logistic regression in which the outcome variable was injury in the last year (Yes/No), as well as relevant statistics.

Variables in the equation	Beta weights (B)	Standard Error (B)	Wald's test	P value	Odds Ratio - Exp(B)	95% C.I. for Exp(B) Lower	Upper
Please indicate how many different surfaces you run on regularly (at least once every two weeks)			17.092	.001			
Running on 2 surfaces (compared to one)	1.329	.380	12.196	.000	**3.776**	1.791	7.958
Running on 3 surfaces (compared to one)	1.483	.424	12.214	.000	**4.407**	1.918	10.124
Running on 4+ surfaces (compared to one)	.574	.501	1.312	.252	**1.775**	.665	4.739
What is your highest level of competition? (competitive, recreational, no competitions)			5.524	.063			
Recreational (compared to competitive)	-.824	.352	5.469	.019	**.439**	.220	.875
No competition (compared to competitive)	-.665	.536	1.538	.215	**.514**	.180	1.471
Age (years)	-.033	.016	4.315	.038	**.968**	.939	.998
How many years has running been a regular part of your life? (i.e. running more than an average 3 days per week) (years)	-.046	.018	6.521	.011	**.955**	.922	.989
What percentage of your total typical running volume (in the last year) is undertaken at an easy to moderate intensity (i.e. just normal running where you can hold a conversation)? Please include your warm up and cool down runs here. - Percentage at easy/mod intensity:	.013	.006	4.553	.033	**1.013**	1.001	1.026
Constant	1.421	.733	3.759	.053	4.140		

Variables not in the equation	Sig.
Have you used orthotic devices, or prescribed insoles, in the last year? (Yes/No)	0.121
How many pairs of different shoe types would you run in regularly (at least once every 2 weeks in the past year for at least a two month period)?	0.552
Number of other sports or exercise activities participated in regularly (at least once every two weeks).	0.407
Have you ever made any conscious/deliberate effort to change your running technique? (Yes/No)	0.311
How many times would you typically run each week (in the last year)?	0.763
How many running sessions per week (in the last year) are high intensity? (I.e. intervals or tempo/threshold runs, where you cannot hold a conversation)?	0.288
In the last year, what distance on average would you typically run in a normal week of training? (km/week)	0.966
How many organized races have you participated in during the last year?	0.709
Gender (Male/Female)	0.706

Table 2
Descriptive statistics of the training choices made by respondents.

Scalar Question	Mean (SD)	95% CI (lower to upper)	Range		
In the last year, what distance on average would you typically run in a normal week of training? - Avg. Km/week;	43 ± 24	40 to 45	3 to 132		
What percentage of your total typical running volume (in the last year) is undertaken at an easy to moderate intensity (i.e. just normal running where you can hold a conversation)? Please include your warm up and cool down runs here. - Percentage at easy/mod intensity:	61 ± 24%	58–64%			
No of participants that reported at least 1 race	89.0% (N = 269)				
How many organized races have you participated in during the last year? (The running section of duathlons/Triathlons etc. may also be included) - Number of organized races:	Median = 6		1 to 72		
In the last year - please indicate any other sports or exercise activities that you participate in regularly (at least once every two weeks). – Number of other activities:	Median = 2		0 to 7		
Multiple choice Question					
How many of your running sessions per week (in the last year) are high intensity? (I.e. intervals or tempo/threshold runs, where you cannot hold a conversation)? - Number of high intensity sessions:	None	One	Two	Three	Four or more
	10.6% (N = 269)	35.8% (N = 115)	36.1% (N = 116	13.1% (N = 42)	4.3% (N = 14)
What is your highest level of competition you participated in during in the last year?	No competition	Recreational	competitive		
	10.8% (N = 33)	(54.6%, N = 165)	34.4% (N = 104)		
Please indicate the surfaces you run on regularly (at least once every two weeks). – Number of different surfaces:	One type	Two types	Three types	Four or more types	
	30% (N = 94)	33.5% (N = 105)	24.9% (N = 78)	11.5% (N = 36)	

the injury, and a further 4.8% (N = 2) reported the orthotic/insole caused a different injury within the following two months. Users reported either using the device in all footwear (31.3%, N = 21), exclusive to running footwear (38.8%, N = 26), or exclusive to non-running footwear (9%, N = 6), and a minority reported either rarely (16.4%. N = 7) or never using them despite the prescription (4.5%, N = 3).

When asked if they have become interested in barefoot running (or ultra-minimal shoes such as foot gloves) at any stage in their running, 27.8% (N = 88) of respondents said yes, and 72.2% (N = 228) said no. Within the "yes" group, only 30.7% (N = 27) reported spending more than one month running barefoot or in ultra-minimal shoes, and only 33% (N = 9) of these are still doing so. The reasons for both continuing and stopping running barefoot or in ultra-minimal shoes are presented in Table 3, where the most popular reason for stopping was as a result of issues with calf pain.

Fig. 1. The anatomical location and distribution of individual injuries reported as a percentage.

When we asked if participants had ever made any conscious/deliberate effort to change their running technique, 62.5% (N = 192) said yes. The reasons presented for making attempts to change technique were improving performance, reducing injury risk, or trying to fix a current injury. The specific methods employed by respondents are presented in Table 4. 42.6% (N = 80) of respondents felt that their running style changed permanently, 9.6% (N = 18) tried for a while before giving up, and 47.9% (N = 90) reported ongoing efforts to change. When asked to report their foot strike, 23.6% (N = 74) reported they have a rearfoot strike, 45.5% (N = 143) a midfoot strike, 19.7% (N = 62) a forefoot strike, and 11.1% (N = 35) reporting unknown foot strike pattern.

The backwards conditional logistic regression identified several potential predictors of injury (Omnibus $\chi2$ (df = 8) = 39.31, $P \leq 0.001$, $R^2 = 0.145$ (Cox & Snell), 0.205 (Nagelkerke R^2). The model explained 20% of the variance in injury selection (Nagelkerke R^2) and was able to identify 73% of cases accurately. The sensitivity was 89.1% and specificity was 36.4%. The model variables that were predictive of injury included number of running surfaces ($p = 0.001$), competition level ($p = 0.063$), age ($p = 0.038$), running age ($p = 0.011$), and proportion of running at an easy intensity ($p = 0.033$). Variables included (as well as odds ratios and confidence intervals) and those not included in the model can be observed in Table 1.

4. Discussion

The main outcome of the present study is that self-reported injury incidence remains high (68.3%) with an even distribution of injuries in the foot, knee, ankle, calf/shin, and hip/groin. This research also identified a large variation in the training, shoe and technique choices of runners. Our regression model identified a

Table 3
Reasons for continuing or stopping to run either barefoot or in ultra-minimal shoes. Brand references have been replaced with footwear type.

Reasons for continuing (N = 9)	Reasons for stopping (N = 17)
Use it as an adjunct for foot muscle specific training.	Winter weather is colder, don't like training in [ultra-minimal shoes] on the road
Running barefoot has helped reduce my hip injuries	Unable to find the exact ones I used to run with and new ones I want to try do not have my size yet.
Run faster	Too many pulled calf muscles
Research supports their use	Tight calves
It helps us to move and run the way humans were designed to and have been doing for the past thousands of years	The shoe I was using went out of production and my local shop didn't have a similar shoe that fit
Improve foot muscles	Stress fracture
I don't get shin splints or suffer from plantar fasciitis since I moved to barefoot/minimalist 3 years ago	Serious knee injury
For a more natural feeling run, I feel like my running form is better in minimal shoes. I enjoy those runs more	Nowhere to run
Find them good for speed sessions	My calf muscles were becoming too sore. My flexibility was not as good as needed.
	Changed to shoes with 4 mm drop
	Longer distances. Ran up to a half marathon with minimal
	It is quite unusual in the running community in Hong Kong
	Injury
	I still run in shoes with a low heel-toe offset and wide toe-box but needed shoes with more cushion due to the mileage I am running
	Found a minimal drop alternative that still offered support
	Easy to get injuries, not comfortable
	Didn't find it made much difference
	Could not increase mileage. Calf and foot pain

number of potential predictors of injury; these include competitive running, running on more than one surface, younger age, having a lower running age, and a higher proportion of running at an easy intensity. We consider the 20% explained variance reasonable for a complex anomaly such as injury; however the model was weak in its ability to predict uninjured runners (36.4%). Several of the factors identified in our regression model are inconsistent with previous research, and indeed a large issue with injury research is the inconsistency of correlates with injury (Murphy et al., 2003; van Gent et al., 2007). It appears that the manifestation of particular injuries is a multifactorial anomaly largely determined by a number of factors (Nielsen, Buist, Sorensen, Lind, & Rasmussen, 2012), and establishment of a definitive list of running risk factors is challenging.

The high proportion of injuries reported here is consistent with other recent self-report evidence (Hespanhol Junior, Costa, Carvalho, & Lopes, 2012; Wiegand et al., 2019), although results vary in the wider literature from 3.2% to 84.9% of runners becoming injured with a given time period, likely due to comparisons of varying populations (Kluitenberg, van Middelkoop, Diercks, & van der Worp, 2015). With regard to the site of injury, our research suggests the majority of injuries experienced by runners occur in the lower extremity, which is also consistent with a recent systematic review (Francis, Whatman, Sheerin, Hume, & Johnson, 2019). The high proportion of lower extremity injuries is likely the lower extremity experiencing a high level of repetitive muscle activation during absorption and propulsion of the running step cycle. Regardless, for injury to occur the runner must be exposed to stressors with inadequate recovery time (Edwards, 2018), and the frequency and severity of such stressors is likely determined by the training and technique choices of the athlete.

Table 4
The specific methods attempted by respondents to change their technique and frequency of the response. Note that respondents could select more than one option.

Technique change	N
Whole body posture changes	125
Less heel striking	94
Increasing cadence (steps per minute)	88
Changing landing softness/hardness	83
More heel striking	4
Arm drive	3
Hip control	2
Increasing stride length	2
Legs spaced wider	2
Attempting to correct external rotation of leg and foot	1
Foot posture	1
Heel in line with knee on flight phase	1
Less forefoot striking	1
Maintain the knee joint position without any lateral/medial turn	1
More pronation	1
Shorter stride length	1

The regression model identified a number of potential factors that were associated with injury and these should be explored further as some of the present findings do not support previous research. Injury occurrence was associated with being competitive as opposed to recreational or no competition, which is supported by previous work (Alonso et al., 2010; van Mechelen, 1992), however this also contradicts other previous research suggesting recreational runners experience more injuries than competitive runners (Tonoli, Cumps, Aerts, Verhagen, & Meeusen, 2010). Secondly, running on more than one surface was found to increase injury risk in the present study, but data from other studies did not find an association between lower extremity injuries and running surface (Macera et al., 1989; Taunton et al., 2003) although these studies did not explore multiple surface use. Being younger was also considered a risk factor, which supports previous evidence (Buist et al., 2010). Similarly a lower running age (history of running) was also observed to be a risk factor, which is often reported in the literature (Hespanhol Junior, Costa, Carvalho, & Lopes, 2012; Knobloch et al., 2008; Macera et al., 1989; Taunton, 2002; Tonoli, Cumps, Aerts, Verhagen, & Meeusen, 2010) and supports the "healthy runner effect" theory in which runners are more likely to stay in the sport as they age if fewer injuries are sustained (Marti, Vader, Minder, & Abelin, 1988). Finally, increasing the percentage of total running volume at an easy to moderate intensity was also associated with increased injury risk; This observation suggests increasing high intensity running decreases injury risk, which is supported by Hespanhol et al., (2013) who observed that increasing high intensity interval volume was a protective factor against injury. Our findings are interesting in that they suggest that the proportion of intensity-specific training may be more predictive of injury than overall total training volume, which is supported by others (Hunter, Garcia, Shim, & Miller, 2019; van Gent et al., 2007; Yeung & Yeung, 2001).

Despite the high frequency of respondents that reported their use and positive outcomes, orthotic use was not associated with injury, which is in agreement with past research (Mattila et al., 2011) but conflicts with recent evidence suggesting orthotics are a risk factor for injury (Chang et al., 2012; Van Der Worp et al., 2015). Given that previous research on orthotics and injury report contradicting findings (Bonanno, Landorf, Munteanu, Murley, & Menz, 2017; Stefanyshyn & Hettinga, 2006), orthotic use should be explored further in future experimental trials.

Training factors that change the foot-ground interaction such as the number of different running footwear, in-shoe devices, or variability of movement such as the number of other sports or technique choices were not associated with injury in the present work. Whilst there is extremely limited research exploring this idea of variability of the foot-ground interaction, Malisoux et al. (2015) observed that running in more than one pair of shoes, as well as participating in more than one sport, were protective factors for injury. The underlying theory suggested by Malisoux and colleagues (2015) was that variation in running shoes and practice of other sports causes a variation in the physical stress applied to the musculoskeletal system, but the current study does not support this contention. Indeed, Satterthwaite, Norton, Larmer, & Robinson, 1999 identified that participation in cycling and aerobics were specific risk factors for thigh and hamstring injuries in marathon runners, and early research reported a link between shin injuries and use of multiple running shoes (Wen et al., 1998), although more recent evidence is lacking. Therefore, variation in footwear and additional sport participation requires substantial investigation in the future for any consensus to be achieved.

We note that an overwhelming observation in this study is the heterogeneity of training choices of the participants and again emphasise that heterogeneity both within and between studies is a likely reason why the body of injury research is so equivocal. The responses in the present study indicate a worrying trend in a high number of races in a year when compared to the average of 8 (Running USA, 2019); 61.5% of respondents reported eight or less races, and 20.7% reported nine to sixteen races, but 17.8% indicated racing more than seventeen races a year (of which 8.6% raced twenty five or more races, or a race every two weeks). Respondents also reported only 61% of their training was conducted at a low intensity which is considerably lower than the ~80% reported in trained and elite endurance athletes (Stöggl & Sperlich, 2015). Respondents also reported a total of sixteen different running technique changes. Recreational runners likely obtain training advice from mostly anecdotal sources and thus lack the information to make the best choices for them as an individual. We suggest that the large variation reported in the present study in all aspects of training may be a significant factor in the injury incidence of today. It appears that runners are willing to adopt many practices despite a lack of scientific evidence; this suggestion is not new, for example footwear prescription has been found to lack substantial evidence despite widespread commercial and professional recommendations (Richards et al., 2009).

There are several limitations of the present study; primarily, this is a self-report survey with a small representative sample, and also recall and volunteer bias may be present. Second, recent evidence (Kluitenberg et al., 2016) suggests that injury definition has a major impact on self-reported injury incidence and therefore we cannot be sure how our injury definition was interpreted. In addition to the definition of injury, self-report rather than clinical confirmation is also a source error; Gabbe, Finch, Bennell, & Wajswelner, 2003 noted that all athletes in their study were able to recall if they were injured in the last year, but when required to provide more detail such as location/diagnosis and number of injuries, this recall dropped to 61%; this observation may be particularly true of our study in which a lot of specific training details were investigated. Third, self-reported foot strike pattern were not included in the regression model due to a high proportion of runners not knowing the answer, which is supported by recent evidence suggesting runners cannot accurately report their foot strike (Goss & Gross, 2012, pp. 25–30). We note that the distribution of reported foot strike patterns in this cohort differs from these previous reports (Goss & Gross, 2012, pp. 25–30), in particular the low rear-foot strike frequency reported in our study. Finally, our study observed a 43% completion rate which may reflect the length and depth of the questions involved, however exploring such a multi-factorial practice requires multiple responses and this could not be avoided. In addition, the use of social media instead of direct recruitment may also reduce the completion rate as participants are not directly invested in assisting with the study completion, but the benefits of the wide reach of social media and more diverse sample make this practice worthwhile.

5. Conclusion

Our research suggests that running injury proportions remain high in line with recent published literature, and also confirm that the most frequent injury locations are the lower extremity such as the foot, ankle, knee and hip. Observed factors associated with injury were competitive running, running on more than one surface, younger age, having a lower running age, and the proportion of running at an easy intensity. These factors associated with injury should be explored in future research further. The high amount of variability in runner's choices highlights the lack of consistent information being presented to them and we suggest this is the reason for the heterogeneity in injury literature.

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Ethical approval

Independent ethical approval was granted in Technological University Dublin, Indiana University, Hong Kong Polytechnic University, and Deakin University. The survey involved a digital informed consent that was completed prior to beginning the survey questions, and tis was mandatory for all participants.

Declaration of competing interest

None declared.

References

Alonso, J.-M., Tscholl, P. M, Engebretsen, L, Mountjoy, M, Dvorak, J, & Junge, A (2010). Occurrence of injuries and illnesses during the 2009 IAAF world athletics championships. *British Journal of Sports Medicine, 44*(15), 1100–1105. https://doi.org/10.1136/bjsm.2010.078030

Bonanno, D. R., Landorf, K. B, Munteanu, S. E, Murley, G. S, & Menz, H. B (2017). Effectiveness of foot orthoses and shock-absorbing insoles for the prevention of injury: A systematic review and meta-analysis. *British Journal of Sports Medicine, 51*(2), 86–96. https://doi.org/10.1136/bjsports-2016-096671

Buist, I., Bredeweg, S. W, Bessem, B, Van Mechelen, W, Lemmink, K. A. P. M, & Diercks, R. L (2010). Incidence and risk factors of running-related injuries during preparation for a 4-mile recreational running event. *British Journal of Sports Medicine, 44*(8), 598–604. https://doi.org/10.1136/bjsm.2007.044677

Chang, W.-L., Shih, Y.-F., & Chen, W.-Y. (2012). Running injuries and associated factors in participants of ING Taipei Marathon. *Physical Therapy in Sport, 13*(3),

170–174. https://doi.org/10.1016/J.PTSP.2011.08.001. Churchill Livingstone.
Costa, M. E. F., Fonseca, J. B, Oliveira, A. I. S, Araujo, M. das G. R, & Ferreira, A. P. L (2020). Prevalence and factors associated with injuries in recreational runners: A cross-sectional study. *Revista Brasileira de Medicina do Esporte. Sociedade Brasileira de Medicina do Exercício e do Esporte, 26*(3), 215–219. https://doi.org/10.1590/1517-869220202603190923
Craig, D. I. (2008). Medial tibial stress syndrome: Evidence-based prevention. *Journal of Athletic Training, 43*(3), 316. https://doi.org/10.4085/1062-6050-43.3.316. National Athletic Trainers Association.
Edwards, W. B. (2018). Modeling overuse injuries in sport as a mechanical fatigue phenomenon. *Exercise and Sport Sciences Reviews, 46*(4), 224–231. https://doi.org/10.1249/JES.0000000000000163
Francis, P., Whatman, P, Sheerin, K, Hume, P, & Johnson, M. I (2019). The proportion of lower limb running injuries by gender, anatomical location and specific pathology: A systematic review. Dept. of Sports Medicine, Medical Faculty of Uludag University *Journal of Sports Science & Medicine, 18*(1), 21–31. Available at: http://www.ncbi.nlm.nih.gov/pubmed/30787648 Accessed: 17 April 2020.
Gabbe, B. J., Finch, C. F, Bennell, K. L, Wajswelner, H, et al. (2003). How valid is a self reported 12 month sports injury history? *British Journal of Sports Medicine, 37*(6), 545–547. https://doi.org/10.1136/bjsm.37.6.545. British Association of Sport and Excercise Medicine.
van Gent, R. N., Siem, D, van Middelkoop, M, van Os, A. G, Bierma-Zeinstra, S. M. A, & Koes, B. W (2007). Incidence and determinants of lower extremity running injuries in long distance runners: A systematic review. BMJ Publishing Group *British Journal of Sports Medicine, 41*(8), 469–480. https://doi.org/10.1136/bjsm.2006.033548. discussion 480.
Goss, D. L., & Gross, M. T. (2012). *Relationships among self-reported shoe type, footstrike pattern, and injury incidence*. US Army Med Dep J. Oct-Dec.
Hamill, J., van Emmerik, R. E. A, Heiderscheit, B. C, & Li, L (1999). A dynamical systems approach to lower extremity running injuries. *Clinical Biomechanics, 14*(5), 297–308. https://doi.org/10.1016/S0268-0033(98)90092-4
Hamill, J., Palmer, C., & Van Emmerik, R. E. A. (2012). Coordinative variability and overuse injury. *Sports Medicine, Arthroscopy, Rehabilitation, Therapy & Technology, 4*(1), 45. https://doi.org/10.1186/1758-2555-4-45. BioMed Central.
Hespanhol Junior, L. C., Costa, L. O. P, Carvalho, A. C. A, & Lopes, A. D (2012). A description of training characteristics and its association with previous musculoskeletal injuries in recreational runners: A cross-sectional study. *Revista Brasileira de Fisioterapia, 16*(1), 46–53. https://doi.org/10.1590/S1413-35552012005000005
Hespanhol Junior, L. C., Pena Costa, L. O., & Lopes, A. D. (2013). Previous injuries and some training characteristics predict running-related injuries in recreational runners: A prospective cohort study. *Journal of Physiotherapy, 59*(4), 263–269. https://doi.org/10.1016/S1836-9553(13)70203-0
Hunter, J. G., Garcia, G. L, Shim, J. K, & Miller, R. H (2019). Fast running does not contribute more to cumulative load than slow running. *Medicine & Science in Sports & Exercise, 51*(6), 1178–1185. https://doi.org/10.1249/MSS.0000000000001888
Kluitenberg, B., van Middelkoop, M, Smits, D. W, Verhagen, E, Hartgens, F, Diercks, R, & van der Worp, H (2015a). The NLstart2run study: Incidence and risk factors of running-related injuries in novice runners. *Scandinavian Journal of Medicine & Science in Sports, 25*(5), e515–e523. https://doi.org/10.1111/sms.12346
Kluitenberg, B., van Middelkoop, M, Diercks, R, & van der Worp, H (2015b). What are the differences in injury proportions between different populations of runners? A systematic review and meta-analysis. *Sports Medicine, 45*(8), 1143–1161. https://doi.org/10.1007/s40279-015-0331-x. Springer International Publishing.
Kluitenberg, B., Middelkoop, M, Verhagen, E, Hartgens, F, Huisstede, B, Diercks, R, & van der Worp, H (2016). The impact of injury definition on injury surveillance in novice runners. *Journal of Science and Medicine in Sport, 19*(6), 470–475. https://doi.org/10.1016/J.JSAMS.2015.07.003. Elsevier.
Knobloch, K., Yoon, U., & Vogt, P. M. (2008). Acute and overuse injuries correlated to hours of training in master running athletes. *Foot & Ankle International, 29*(7), 671–676. https://doi.org/10.3113/FAI.2008.0671. SAGE PublicationsSage CA: Los Angeles, CA.
Knowles, S. B., Marshall, S. W, Miller, T, Spicer, R, Bowling, J. M, Loomis, D, … Mueller, F. O (2007). *"Cost of injuries from a prospective cohort study of North Carolina high school athletes", Injury Prevention* (Vol. 13, pp. 416–421). BMJ Publishing Group Ltd, 6.
Kozinc, Ž., & Sarabon, N. (2017). Common running overuse injuries and prevention. *Montenegrin Journal of Sports Science and Medicine, 6*(2), 67–74. https://doi.org/10.26773/mjssm.2017.09.009
Kurz, M. J., & Stergiou, N. (2003). The spanning set indicates that variability during the stance period of running is affected by footwear. *Gait & Posture, 17*(2), 132–135. https://doi.org/10.1016/S0966-6362(02)00064-4
Lee, D., Brellenthin, A. G, Thompson, P. D, Xuemei, S, Lee, I-Min, & Lavie, C. J (2017). Running as a key lifestyle medicine for longevity. *Progress in Cardiovascular Diseases*. Available at: http://pilarmartinescudero.es/MarzoAbrilMayoJunio2017/Running as a Key lifestyle medicine for longevity.pdf Accessed: 9 April 2020.
Macera, C. A., Pate, R. R, Powell, K. E, Jackson, K. L, Kendrick, J. S, & Craven, T. E (1989). Predicting lower-extremity injuries among habitual runners. *Archives of Internal Medicine, 149*(11), 2565. https://doi.org/10.1001/archinte.1989.00390110117026. American Medical Association.
Malisoux, L., Ramesh, J, Mann, R, Seil, R, Urhausen, A, & Theisen, D (2015). Can parallel use of different running shoes decrease running-related injury risk? *Scandinavian Journal of Medicine & Science in Sports, 25*(1), 110–115. https://doi.org/10.1111/sms.12154
Marti, B., Vader, J. P, Minder, C. E, & Abelin, T (1988). On the epidemiology of running injuries. *The American Journal of Sports Medicine, 16*(3), 285–294. https://doi.org/10.1177/036354658801600316. SAGE Publications.
Mattila, V. M., Sillanpaa, P. J, Salo, T, Laine, H. J, Maenpaa, H, & Pihlajamaki, H (2011). Can orthotic insoles prevent lower limb overuse injuries? A randomized-controlled trial of 228 subjects. *Scandinavian Journal of Medicine & Science in Sports, 21*(6), 804–808. https://doi.org/10.1111/j.1600-0838.2010.01116.x. John Wiley & Sons, Ltd.
van Mechelen, W. (1992). Running injuries. *Sports Medicine, 14*(5), 320–335. https://doi.org/10.2165/00007256-199214050-00004
Murphy, D. F. (2003). Risk factors for lower extremity injury: A review of the literature. *British Journal of Sports Medicine, 37*(1), 13–29. https://doi.org/10.1136/bjsm.37.1.13
Murphy, D., Connolly, D., & Beynnon, B. (2003). Risk factors for lower extremity injury: A review of the literature. *British Journal of Sports Medicine, 37*(1), 13. https://doi.org/10.1136/BJSM.37.1.13. BMJ Publishing Group.
Nielsen, R.Ø., Parner, E. T, Nohr, E. A, Sorensen, H, Lind, M, & Rasmussen, S (2014). Excessive progression in weekly running distance and risk of running-related injuries: An association which varies according to type of injury. *Journal of Orthopaedic & Sports Physical Therapy, 44*(10), 739–747. https://doi.org/10.2519/jospt.2014.5164. JOSPT, Inc. JOSPT, 1033 North Fairfax Street, Suite 304, Alexandria, VA 22134-1540.
Nigg, B. M., Vienneau, J, Smith, A. C, Trudeau, M. B, Mohr, M, & Nigg, S. R (2017). The preferred movement path paradigm. *Medicine & Science in Sports & Exercise, 49*(8), 1641–1648. https://doi.org/10.1249/MSS.0000000000001260
Nielsen, R. O, Buist, I, Sorensen, H, Lind, M, & Rasmussen, S (2012). Training errors and running related injuries: A systematic review. *The International Journal of Sports Physical Therapy, 7*(1), 58–75.
Putukian, M. (2016). The psychological response to injury in student athletes: A narrative review with a focus on mental health. *British Journal of Sports Medicine, 50*(3), 145–148. https://doi.org/10.1136/BJSPORTS-2015-095586. BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine.
Richards, C. E., Magin, P. J., & Callister, R. (2009). Is your prescription of distance running shoes evidence-based? *British Journal of Sports Medicine, 43*(3), 159–162. https://doi.org/10.1136/bjsm.2008.046680
Running, U. S. A. (2019). 2019 running USA U.S. Running trends report. Available at: https://runningusa.org/RUSA/News/2019/Running_USA_Releases_2019_U.S._Running_Trends_Report.aspx Accessed: 1 July 2020.
Saragiotto, B. T., Yamato, T. P., & Lopes, A. D. (2014). What do recreational runners think about risk factors for running injuries? A descriptive study of their beliefs and opinions. *Journal of Orthopaedic & Sports Physical Therapy, 44*(10), 733–738. https://doi.org/10.2519/jospt.2014.5710
Satterthwaite, P., Norton, R, Larmer, P, & Robinson, E (1999). Risk factors for injuries and other health problems sustained in a marathon. *British Journal of Sports Medicine, 33*(1), 22. https://doi.org/10.1136/BJSM.33.1.22. BMJ Publishing Group.
Stefanyshyn, D., & Hettinga, B. (2006). Running injuries and orthotics: Review article. Human Kinetics Publishers *International SportMed Journal, 7*(2), 109–119. Available at: https://journals.co.za/content/ismj/7/2/EJC48589 Accessed: 1 July 2020.
Stöggl, T. L., & Sperlich, B. (2015). The training intensity distribution among well-trained and elite endurance athletes. *Frontiers in Physiology, 6*, 295. https://doi.org/10.3389/fphys.2015.00295
Taunton, J. E. (2002). A retrospective case-control analysis of 2002 running injuries. *British Journal of Sports Medicine, 36*(2), 95–101. https://doi.org/10.1136/bjsm.36.2.95
Taunton, J. E., Ryan, M. B, Clement, D. B, McKenzie, D. C, Lloyd-Smith, D. R, & Zumbo, B. D (2003). A prospective study of running injuries: The Vancouver sun run "in training" clinics. *British Journal of Sports Medicine, 37*(3), 239–244. https://doi.org/10.1136/BJSM.37.3.239. British Association of Sport and Excercise Medicine.
Tonoli, D. C., Cumps, E, Aerts, I, Verhagen, E, & Meeusen, R (2010). "Incidence , risk factors and prevention of running related injuries in long-distance running : A systematic review". *Sport & Geneeskunde*, (5), 12–18.
Van Der Worp, M. P., Ten Haaf, D. S. M, Van Cingel, R, De Wijer, A, Nijhuis-Van der Sanden, M. W. G, & Bart Staal, J (2015). 'Injuries in runners; a systematic review on risk factors and sex differences. *PLoS ONE. Public Library of Science, 10*(2), 1–18. https://doi.org/10.1371/journal.pone.0114937
Van Gent, R. N., Siem, D, van Middelkoop, M, van Os, A. G, Bierma-Zeinstra, S. M. A, & Koes, B. W (2007). Incidence and determinants of lower extremity running injuries in long distance runners: A systematic review. *Sport en Geneeskunde, 40*(4), 16–29. https://doi.org/10.1136/bjsm.2006.033548
Videbæk, S., Bueno, A. M, Nielsen, R. O, & Rasmussen, S (2015). Incidence of running-related injuries per 1000 h of running in different types of runners: A systematic review and meta-analysis. *Sports Medicine, 45*(7), 1017–1026. https://doi.org/10.1007/s40279-015-0333-8
Warne, J. P., & Gruber, A. H. (2017). Transitioning to minimal footwear: A systematic review of methods and future clinical recommendations. *Sports Medicine - Open, 3*(1). https://doi.org/10.1186/s40798-017-0096-x
Wen, D. Y., Puffer, J. C., & Schmalzried, T. P. (1998). Injuries in runners: A prospective study of alignment. *Clinical Journal of Sport Medicine, 8*(3), 187–194. https://doi.org/10.1097/00042752-199807000-00005
Wiegand, K., Mercer, J. A, Navalta, J. W, Pharr, J, Tandy, R, & Freedman-Silvernail, J

(2019). Running status and history: A self-report study. *Physical Therapy in Sport, 39*, 8—15. https://doi.org/10.1016/j.ptsp.2019.06.003
Yeung, E., & Yeung, S. (2001). A systematic review of interventions to prevent lower limb soft tissue running injuries. *British Journal of Sports Medicine, 35*(6), 383. https://doi.org/10.1136/BJSM.35.6.383. BMJ Publishing Group.
Yeung, S. S., Yeung, E. W., & Gillespie, L. D. (2011). Interventions for preventing lower limb soft-tissue running injuries. *Cochrane Database of Systematic Reviews*, (7)https://doi.org/10.1002/14651858.CD001256.pub2. CD001256.